OVERVIEW
Total Maximum Daily Load (TMDL) for Total Phosphorous for Lake Okeechobee

Today, under the Total Maximum Daily Load (TMDL) Program, the Environmental Protection Agency Region 4 (EPA-R4) is proposing a total annual load for total phosphorous for Lake Okeechobee in South Florida. In developing the proposed total annual load, EPA-R4 worked closely with the State of Florida Department of Environmental Protection (FDEP), the South Florida Water Management District (SFWMD), and with EPA=s Office of Wetlands, Oceans and Watersheds in the Office of Water, EPA Headquarters. EPA also attended several FDEP sponsored workshops on this issue, and listened to comments from various stakeholders. This proposed TMDL identifies the maximum load of phosphorus the Lake can receive and ultimately be restored (brought into compliance with water quality standards). The TMDL allocates the total load reduction to all the non-point sources combined. A specific allocation of the TMDL to the major pollutant sources in the basin and the implementation plan for the TMDL are to be established in future efforts. EPA is proposing that a collaborative process with the State and local stakeholders be established to accomplish this.

The TMDL is described in a separate document (Total Maximum Daily Load (TMDL) Development for Total Phosphorus-Lake Okeechobee, Florida, January 3, 2000), which also contains the technical analysis EPA conducted in the development of the TMDL. EPA is also providing this Overview, which is not part of the proposed TMDL, to provide background on Lake Okeechobee and the water quality problems that led to the need to establish a TMDL, and the issues EPA considered in the development of the TMDL. EPA has also included a description of the proposed collaborative process and is seeking public comment on all of these issues.

Lake Okeechobee-History and Summary of Problem

Lake Okeechobee is a large, shallow (average depth 2.7 meters) freshwater lake with a surface area covering 730 square miles. It is the largest freshwater lake in Florida and the second largest freshwater lake in the contiguous United States excluding the Great Lakes. Since it is a source of drinking water, the State has designated Lake Okeechobee as a Class I water body. It is also a source of irrigation water, recharges the Upper Floridan aquifer, provides habitat for fish spawning and waterfowl, and provides for flood control, navigation and recreation. Lake Okeechobee serves as the primary source of water for the Everglades system. Lake Okeechobee is a complex system that, depending upon the habitat, has varied nutrient levels throughout the system. There is a large shallow littoral zone along the southern and western edges of the Lake with emergent and submerged vegetation. The balance of the Lake is a relatively shallow open water area. It also has complex water circulation patterns that are primarily controlled by wind events. As discussed below, these wind-driven events play a significant role in the water quality problems in the Lake.

The Lake has been significantly impacted over the past 60 or more years by hydrologic and land-use modifications to its drainage basin and by the construction of the Hoover Dike and Lake-level manipulation. These watershed land use practices include farming that increased the nutrient and sediment load into the Lake. Historically, the Lake had few natural outlets that drained the Lake. As water levels increased in the Lake, the water would flow over the natural low berm, and move south into the Everglades. This provided natural seasonal flows into the Everglades system and allowed the Lake to be periodically flushed out. As a result of major hurricane driven rainfall events that flooded communities next to the Lake, starting in the 1930's, the Hoover Dike was built around the Lake to prevent this flooding. Large canals were also constructed with water control structures to manage the water levels in the Lake. Additional canals were dug, along with the creation of the Water Conservation Areas south of the Lake as part of the Central and South Florida Project. After these hydrological modifications, the water discharged from the Lake moved down canals, south to the Everglades and east and west to the estuaries. This system resulted in higher average Lake water levels, longer water retention times within the Lake, and restricted the natural flooding of the adjacent system south of the Lake. It also interrupted the natural flow into the historic Everglades.

This modified system functioned well for flood control and supplying irrigation water to the adjacent farms south of the Lake, but also had unintended negative effects on Lake water quality. As farms developed south of the Lake, irrigation runoff and agricultural stormwater containing large quantities of nutrients were pumped north into the Lake. Farming in the watersheds north of the Lake caused large amounts of sediments and nutrients to be discharged into the Lake. These activities resulted in large amount of sediments containing significant levels of nutrients to accumulate in the Lake. Without the natural flushing that occurred when the Lake drained over the historic low natural berm, this sediment continued to accumulate in the Lake over the last 60 years. These sediments are now frequently resuspended by wind events resulting in the nutrients being released back into the water column, causing violations of water quality standards and the Lake to not meet its designated uses.

Recognizing the nutrient loading problems, the pumping into the Lake from the farms south of the Lake are being phased out over time. Also, the State has implemented several programs to reduce the nutrient load from the watersheds north of the Lake. These efforts include the Works of the District Program, the Dairy Rule and the Dairy Buy-Out Program among others. These efforts have reduced the nutrient load into the Lake, but it is widely recognized that additional reductions in the amount of phosphorus being discharged into the Lake and some form of internal remedial efforts will be needed in order to restore the Lake in a reasonable period of time. This restoration is critical not only for the Lake itself, but for the downstream Everglades, which relies on the Lake as a source of water.

The TMDL Process

In order to restore the Lake (bring it into compliance with water quality standards), the maximum amount of phosphorus that the Lake can receive and reach this goal must be identified. That is the purpose of the TMDL process. The TMDL program was established under the Clean Water Act (CWA) in order to restore the nation=s waters so that waters not meeting water quality standards are restored. Under Section 303(d) of the Clean Water Act (CWA), TMDLs are required to be developed for all waters that have been identified as impaired (not meeting the applicable water quality standard). Specifically, a TMDL is defined in Section 303(d)(1)(C), as Athe load . . . . necessary to implement the applicable water quality standards with seasonal variability and a margin of safety . . . .@ In other words, the TMDL will identify the amount of phosphorus the Lake can receive so that the Lake is meeting the nutrient water quality standard in some reasonable period of time, and will maintain the Lake in this condition once it is restored.

A water quality standard establishes the water quality goals of a water body by identifying the designated use(s) of the water and setting water quality criterion to protect those uses. There are various categories of designated uses that determine the level of water quality protection that is necessary for a body of water. In this case, the State has identified the designated use of Lake Okeechobee as a Class I water body, a source of drinking water since it supplies the drinking water for many surrounding communities.

Following the requirements of the CWA, in 1998 the State of Florida submitted and EPA approved, a list of impaired waters for the State. That list included Lake Okeechobee as impaired for nutrients that triggered the TMDL development requirement. Under the TMDL program, the State has the primary responsibility to develop the TMDLs for the listed waters. But in addition to the CWA requirements, EPA-R4 is also operating under the terms of a Consent Decree that required EPA to approve a State established Lake Okeechobee TMDL by December 31, 1999, or EPA was required to propose a TMDL by that date. (See, Florida Wildlife Federation et al v. Carol Browner et al., Case No. 98-356-CIV-Stafford). Like the CWA, the terms of the Consent Decree gives the State of Florida the opportunity to develop any TMDL.

However, because of new State TMDL rule-making procedures, the State was not able to finalize a TMDL for Lake Okeechobee such that EPA could approve it by the December 31, 1999 date in the Consent Decree. EPA, as a signatory to the Consent Decree, was required to propose the Lake Okeechobee TMDL in lieu of the State. Under the Consent Decree the State, at any time, may submit to EPA, a final TMDL for Lake Okeechobee for EPA review and approval or disapproval. If EPA approves a State TMDL, the State TMDL will supersede any previously proposed or final TMDL established by EPA. Recognizing the State's primary responsibility in this process, as noted above, EPA relied heavily on information developed by the State of Florida in proposing this TMDL.

Background on TMDL Development

The Lake Okeechobee TMDL presented a unique situation unlike any other TMDL proposed by EPA-R4, by EPA nationally, or by any EPA-R4 state. As such, many special factors were required to be considered throughout the process of developing this TMDL. The accompanying TMDL document explains in detail the complexities of the Lake Okeechobee system that were considered in calculating the TMDL. A discussion of these considerations is also provided in this overview to help readers understand the issues faced by EPA and the analysis done in proposing today's Lake Okeechobee TMDL. There were also complex issues associated with the calculation of the TMDL such as developing the target goal and addressing the assimilative capacity of the Lake (the assimilative capacity of a water body is the amount of a pollutant that can be taken up by the water body while meeting water quality standards).

TMDLs are typically developed using a computer-based model. In this case, the TMDL was calculated using the South Florida Water Management District's (SFWMD's) Lake Okeechobee Water Quality Model (LOWQM) which was developed by the SFWMD as part of their on-going lake restoration program. EPA chose to use this model since it had been peer reviewed and had already been calibrated by the SFWMD for the Lake. The model takes a restoration target goal (or numeric water quality standard if available), and using the data available on the Lake, calculates the amount of phosphorus load the Lake can receive and meet the goal or standard. It can then be used to predict the length of time it will take the Lake to reach this goal.

Phosphorus Conditions in the Lake

As discussed above, Lake Okeechobee is a large and complex ecosystem that contains distinct ecological regions. It has been impacted for over 60 years by increased nutrient and sediment loads, and changes in the hydrology of the Lake. There is still a substantial phosphorus load (624 metric tons in 1997) entering the system from the watersheds that needed to be considered. Reducing this external source of phosphorus is critical since studies have shown that this load has a negative impact on water quality in the Lake. Reducing this source will also prevent additional accumulation of phosphorus-laden sediments in the Lake. However, due to the existing internal recycling of phosphorus sequestered in the sediments, it will take a substantial period of time for the Lake to be restored in response to the reduction of the phosphorus load entering the Lake from the watershed alone. As noted above, phosphorus rich sediments have accumulated in the Lake over the past 60 years. The current estimate is that the upper 18 inches of sediment contains approximately 30,000 metric tons of phosphorus. During wind events, these sediments are resuspended in the Lake, and the phosphorus contained in the sediments is released into the water column, impacting the water quality. Also, the Lake levels have changed over time and are scheduled to change again under a new regulatory control schedule. The retention time for water in the Lake has also varied over time. Changes in the Lake levels and the increased Lake retention time have also had negative impacts on water quality and should be factored into the restoration process.

Target Goal for the TMDL

The first step in calculating the TMDL is to identify the target goal that is needed to identify the numeric point when the Lake will be successfully restored. The TMDL model uses the target goal, and based on the available data and information on the Lake, calculates the amount of load the Lake can receive and meet the goal. The State of Florida has an EPA-approved narrative water quality criterion for phosphorus. This narrative criterion (Rule 62-302.530(48)) establishes that: AIn no cases shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna.@ However, the State of Florida, like many states, has not established a numeric water quality criterion for nutrients, including phosphorus, for lakes. A numeric criterion interprets the narrative criterion by identifying a specific number that will protect the designated use of the water body (the water quality). Without a numeric water quality criterion being available for the development of the TMDL, it was necessary for EPA-R4 to identify a numeric target goal for phosphorous for the Lake that is expected to restore the Lake=s water quality and protect the designated use.

Lake Okeechobee is ecologically complex, and there is a range of nutrient concentrations that would naturally exist in different areas of the restored Lake. However, the model requires a single number for analysis, and it was necessary to choose a lake-wide average. The State and others have conducted different studies over the last several years, and the total in-lake average water column phosphorous concentrations that were predicted to maintain the designated use of the Lake ranged from 34 ppb to 75 ppb. EPA-R4 reviewed the various studies, consulted with FDEP and the SFWMD, and attended several workshops held by the State to discuss these issues. Based on the review of these studies, available data and comments made at the workshops, EPA selected an average lake-wide water column phosphorous concentration target for the TMDL of 40 ppb. This target is consistent with the targets identified in the development of the Lake Okeechobee Surface Water Improvement Management Plan (SWIM), and was recently identified as the restoration goal in the Lake Okeechobee Action Plan by the Lake Okeechobee Issue Team, a sub-committee of the South Florida Ecosystem Restoration Working Group.

The TMDL Modeling Scenario

The next step in the process was to consider whether the Lake has any assimilative capacity to accept nutrients. A TMDL is the pollutant load that can be Aassimilated@ by a water body when the water body is at the applicable water quality standard for the pollutant. In other words, at a point in the future when water quality standards are being met. This establishes the Amaximum assimilative capacity@ of the restored system. EPA believes this approach is appropriate in setting the TMDL where the water quality standard will be met in a reasonable period of time. For example, for many impaired water bodies, such as most flowing rivers, once the load to the water body is reduced to the level established in the TMDL, the water body will be restored to the water quality standard in a relatively short period of time. However, for a lake system such as Lake Okeechobee, with its large volume of water, fairly long water retention time (the time it takes the Lake to be completely flushed out) and the large quantity of phosphorous in the Lake sediments that will continue to be released into the water column, the model predicts it will take more than one thousand years for the Lake to reach the water quality standard using the Amaximum assimilative capacity@ load. As discussed below, because of this predicted restoration time period, EPA concluded it was not reasonable to follow the Amaximum assimilative capacity@ analytical approach for developing the Lake Okeechobee TMDL. However, EPA used this approach as a starting point in considering other loading scenarios.

Restoration Time Frames

In calculating the Lake Okeechobee nutrient TMDL, EPA-R4 first identified the maximum phosphorous load the Lake can handle at a future time when Lake water quality meets the 40 ppb phosphorous target (the Amaximum assimilative capacity@). This analysis was based on available historic data and information on the condition of the Lake before it was impaired. (This information is discussed in the TMDL document). The Amaximum assimilative capacity@ analysis calculated that a maximum load of 285 metric tons of phosphorus could enter the Lake per year and maintain the phosphorus water quality standard. Using this load, absent any other restoration activities, the model predicted it would take between 1000 and 1500 years for the Lake to achieve the standard (based on reducing external loads to the Lake only).

EPA next considered whether this restoration time frame was a reasonable period of time and concluded it was not. EPA believes that selecting a total annual load which would take 1000 to 1500 years for the Lake to reach the water quality target would not meet the underlying requirements of the 1972 Clean Water Act, to restore the nation=s waters. For the main body of Lake Okeechobee, the sources contributing to the phosphorus exceedences are all non-point sources. While neither the CWA nor the TMDL regulations speak to the issue of how long it should take for load allocations assigned to non-point sources to be implemented so that the impaired water body attains the appropriate water quality standard, EPA believes it has an obligation to select a TMDL that will achieve water quality standards within a reasonable time frame taking all factors into account. Clearly a restoration time period of 1000 to 1500 years is not reasonable, especially considering it took only 60 years to cause the impairment.

EPA next utilized the computer model to evaluate a range of loading scenarios, and the resulting time period required for Lake restoration at these various loads. EPA chose this approach to allow the public to see the effect different loading scenarios have on the restoration time frame. Using 40 ppb of phosphorus as the in-lake target, the model produced a series of loading scenarios from a zero in-flow loading (allowing for atmospheric deposition only) to the maximum assimilative capacity load of 285 metric tons. This resulted in predicted restoration time periods ranging from approximately 20 to 30 years (assuming the only load entering the system is the estimated 71 metric tons per year of atmospheric deposition) to approximately 1000 to 1500 years for the Amaximum assimilative capacity@ load of 285 metric tons per year (including atmospheric deposition). For additional loading scenarios, see Table 4, in the TMDL.

Selecting the TMDL

EPA assessed the option of establishing the TMDL at zero for the in-flow loading (assuming the estimated atmospheric deposition only). This is predicted to allow the Lake to meet the water quality target in approximately 20 to 30 years. While this is the fastest time frame for restoration, EPA realized it is not possible to achieve a zero load from external land-based sources because of the significant amounts of phosphorus currently sequestered in the watershed. This option would also require all existing sources to essentially cease discharging. EPA concluded a TMDL of zero loading was not realistically achievable and therefore not reasonable. EPA reviewed the modeling results and considering the range of loadings and restoration time periods produced by the model (See Table 4 in the TMDL document), <u>EPA selected a TMDL of 198 metric tons per year which the model predicts will restore the Lake in approximately 200 to 220 years.</u> EPA recognizes this is a long period of time but believes if the external load is reduced to 198 metric tons per year, and this action is combined with other remedial actions (such as sediment removal) that are being investigated, the restoration time period may be reduced. EPA also considered in its decision (using best professional judgment), that the loading of 198 metric tons is likely achievable, considering the current land uses within the basin. This TMDL represents approximately a 68% reduction in the current watershed phosphorus loads that are discharged into the Lake.

It is important to recognize that as this TMDL is implemented, incremental improvements in the water column phosphorus will occur over time. As can be seen in the graphs in the TMDL document (Figures 10 and 11), reducing the phosphorus load to this level will result in significant near term (30 year) improvements in water quality. It is interesting to note on Figures 10 and 11 that each of the various loading scenarios (except the scenario where only atmospheric deposition was modeled) result in similar reductions in water column concentrations of phosphorus during the first 30 years. The major difference in the various loading scenarios is in how long the model predicted it will take for the Lake to be restored. EPA believes this is due to the large quantity of phosphorus sequestered in the Lake sediments.

Sediment Removal - Impact on Restoration Time Frames

As noted above, a significant quantity of phosphorus has been sequestered in the Lake sediments. In analyzing the various scenarios, it became evident that the current phosphorous load contained in the in-lake sediments has a significant impact on the restoration time periods. Because of EPA=s concern regarding the lengthy predicted time periods for restoration, EPA reviewed work presented by the SFWMD concerning the effect of removing Lake sediments on the predicted restoration time. The SFWMD has looked at various removal rates to determine the effect on water quality and the results are promising, if dredging proves feasible. EPA has given a grant to the SFWMD to continue research into the feasibility of dredging options.

From this analysis, it is apparent that recycling of phosphorus from the sediments has a significant effect on the water column concentrations of phosphorus in parts of the Lake. Although this is clearly an implementation issue that requires further analysis, it is appropriate to point this out since the effect on the restoration time frames is potentially significant. It will be important for the State and stakeholders to identify and implement effective remedial restoration actions as quickly as possible in order to restore the Lake within a reasonable time period. EPA hopes the collaborative process discussed below will lead to this result. EPA expects this TMDL analysis to be updated every ten years or, when necessary, to model the results of the restoration activities and consider new data as it is developed.

Public Comment Opportunity

In proposing the TMDL of 198 metric tons of phosphorus, EPA is seeking public comment on the TMDL, as well as the other scenarios presented. EPA, in the TMDL document, is providing information to the readers of the time frame involved for lake restoration at the proposed TMDL level. EPA, in the TMDL document, is also providing information of the time period required to reach the target goal at various levels of phosphorous loading above and below the proposed TMDL. We are inviting the local stakeholders to consider and provide input on their view as to whether the TMDL is reasonable and appropriate given the required amount of phosphorus load reduction and the time frame predicted for Lake restoration. In making their recommendations, we would be interested in whether stakeholders believe the cost of achieving greater external phosphorous load reductions is worth the benefits of having a cleaner lake in a shorter period of time and why they believe this is so. EPA intends to carefully evaluate the comments received.

The public comment period will be open from January 3, 2000 to March 17, 2000. A public meeting will be scheduled in the middle of the comment period and will be announced in a separate public notice.

Allocation and Implementation Issues - Collaborative Process

The TMDL being proposed today covers Lake Okeechobee proper, which includes six segments identified as impaired for nutrients on the FDEP Section 303(d) list. Each of the associated impaired watersheds (draining to Lake Okeechobee) are identified on the State=s list for separate TMDLs in the future. Since the sources of the impairment that flow directly into the Lake are all non-point sources, EPA has not specifically allocated the TMDL to any one source. Allocation of the TMDL to the watersheds and the development of the implementation plan designed to achieve the TMDL are the final steps in the TMDL process, and EPA has proposed that these be developed through a collaborative process. Allocation and implementation are critical to the ultimate success of the TMDL.

Lake Okeechobee has been the focus of numerous studies over many years that have resulted in a large volume of available data. Over the last 15 years, several efforts have been taken to restore the Lake and many remedial measures are already ongoing. The phase-out of the back-pumping from the southern farms, the Works of the District Program, the FDEP Dairy Rule, the Dairy Buy-Out Program and other measures have been implemented. Also, other remedial measures have been either identified or are in the planning stage at this time. The Central and Southern Florida Comprehensive Review Study (Restudy) identifies many project elements designed to restore the Lake. The Lake Okeechobee Action Plan also recommends many specific actions to restore the Lake. As a result, implementation of remedial measures has already begun and will be an ongoing process requiring an adaptive and dynamic approach.

EPA believes a collaborative process to develop an implementation strategy on Lake Okeechobee restoration is needed due to the complexity of the problem, the wide range of interested parties (and positions) with a stake in the restoration of the Lake and the various efforts underway to restore the system. The nutrient problems in the Lake come from a variety of sources that will require site-specific restoration approaches and the cooperation of many different parties. Also, since Lake restoration is part of the Restudy, and the goal of the recently completed Lake Okeechobee Restoration Action Plan, a collaborative process is needed to coordinate the individual restoration recommendations planned as part of these efforts with the ongoing restoration activities and the TMDL.

EPA is proposing that a collaborative process be established, starting with an existing broad based group (the Lake Okeechobee Issue Team), which has already brought together representatives of the major stakeholder groups. The Lake Okeechobee Issue Team, formed by the South Florida Ecosystem Restoration Working Group, has established a strong consensus on Lake restoration issues. The Issue Team includes state and local representatives involved in management of the Lake, environmentalists, members of the agricultural community and federal representatives. EPA is proposing that this group form the core stakeholders for the collaborative process, with additional parties included as needed so that all the relevant interests are represented.

The goal of the collaborative process will be to develop and explore alternatives and options to allocate and implement the established TMDL for the Lake. The Issue Team formally submitted the Lake Okeechobee Restoration Action Plan to the Working Group at the December 1, 1999 meeting. Due to the make up of the Issue Team, the Action Plan already has widespread support. The Lake Okeechobee Restoration Action Plan sets out a comprehensive set of actions that can be taken to help restore the Lake to 40 ppb, the goal of the original SWIM Plan and the proposed TMDL. Since the Action Plan was developed by consensus, the list of options in the Action Plan can form the starting point for the collaborative process. The group would also consider the Restudy project elements as well as other options, as they are developed and authorized.

Summary of TMDL

The accompanying TMDL document proposes a total annual load for total phosphorus to Lake Okeechobee. The TMDL was calculated using the South Florida Water Management District=s (SFWMD=s) Lake Okeechobee Water Quality Model (LOWQM) which was developed by the SFWMD as part of their on-going lake restoration program. This peer-reviewed model had already been calibrated by the SFWMD for the Lake. The model takes a target water quality goal (or the numeric standard if one has been approved), and using the available information about the Lake, calculates the amount of phosphorus load the Lake can receive and meet the target goal or standard. It can then be used to predict the length of time it will take the Lake to reach the restored condition if the load is attained.

The TMDL was calculated using an in-lake total phosphorus concentration of 40 ppb, which represents an average water column phosphorus level for the entire Lake. The target goal was based on several studies and sets of data and is consistent with published water quality targets for the Lake. Using the model, EPA calculated the phosphorus load that Lake Okeechobee could receive and meet the target goal of 40 ppb at some point in the future. EPA made a series of model runs looking at the effect changing the load had on the time it would take to restore the Lake. This resulted in a series of scenarios that ranged from approximately 1000 to1500 years for an annual load of 285 metric tons of phosphorus, to approximately 20 to 30 years, if only atmospheric deposition (estimated at 71 metric tons per year) is considered. After reviewing this information, EPA is proposing a TMDL for phosphorous for Lake Okeechobee of 198 metric tons per year, with a predicted lake restoration time period of approximately 200 to 220 years. This proposed load of 198 metric tons per year represents approximately a 68% reduction in the 1997 load of 624 metric tons of phosphorus.

EPA also reviewed information provided by the SFWMD concerning the impact sediment dredging, if feasible, would have on the restoration time period. The results look promising and EPA has given a grant to the SFWMD to continue the feasibility research. EPA also noted that when all the loading scenarios were compared (except the atmospheric deposition only scenario), water quality levels showed similar improvement over the first 30 years. The major change was in the length of time it took the Lake to be restored (meeting water quality standards).

Conclusion

In closing, EPA is proposing a TMDL which the Agency considers to be reasonable and appropriate given the anticipated time for Lake restoration, and the Agency=s best professional judgment of what is realistically achievable in loading reductions. EPA is seeking comments on the proposal, and is planning a public meeting in the local area (most likely in February 2000) to provide further opportunity for stakeholder input. All comments received will be carefully considered. EPA will continue to work in cooperation with the State and local stakeholders through a collaborative process in the development of effective remedial measures for Lake restoration.

TOTAL MAXIMUM DAILY LOAD (TMDL) DEVELOPMENT

For Total Phosphorus

LAKE OKEECHOBEE

Florida

EPA United States Environmental Protection Agency

Region 4 serving the southeast

Table of Contents

Table of Figures

Table of Tables

Executive Summary

This document proposes a Total Maximum Daily Load (TMDL) for phosphorus in Lake Okeechobee. Lake Okeechobee is a large, shallow eutrophic lake located in subtropical south central Florida. It is a large multipurpose reservoir providing drinking water for urban areas, irrigation water for agricultural lands, recharge for aquifers, freshwater for the Everglades, habitat for fish spawning and waterfowl, flood control, navigation, and many recreational opportunities. The lake is primarily impaired by phosphorus, which is evidenced by widespread algal blooms in the lake.

The water quality goal of this TMDL is to reduce the total phosphorus load to Lake Okeechobee, in order to control high chlorophyll *a* concentrations, which are indicative of algal blooms.

The TMDL is based on achieving an in-lake total phosphorus concentration of 40 parts per billion (ppb). The target is a conservative estimate that will be used to guide decision making until better information becomes available. The TMDL is calculated using the total phosphorus concentration target of 40 ppb, 26-year average flow (1973-1998), and the assimilative capacity of the lake's sediments. The TMDL for phosphorus is 198 metric tons per year.

Introduction

Section 303(d) of the Clean Water Act (CWA) as Amended by the Water Quality Act of 1987, Public Law 100-4, and the United States Environmental Protection Agency's (USEPA/EPA) Water Quality Planning and Management Regulations [Title 40 of the Code of Federal Regulation (40 CFR), Part 130] require each State to identify those waters within its boundaries not meeting water quality standards applicable to the water's designated uses. The identified waters are prioritized based on the severity of pollution with respect to designated use classifications. Total maximum daily loads (TMDLs) for all pollutants exceeding or causing exceedences of applicable water quality standards are established for each identified waters. Such loads are established at levels necessary to implement the applicable water quality standards with seasonal variations and margins of safety. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a water body, based on the relationship between pollution sources and in-stream water quality conditions, so that states can establish water-quality based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (USEPA, 1991).

Problem Definition

Lake Okeechobee was identified on the 1998 303(d) list, submitted to EPA by the Florida Department of Environmental Protection (DEP), as being impaired by nutrients (phosphorus), dissolved oxygen, un-ionized ammonia, chlorides, coliforms, and iron.

This document proposes a TMDL for phosphorus in Lake Okeechobee. The TMDL is being proposed pursuant to EPA commitments in the June 30, 1999 Consent Decree (Florida Wildlife Federation et. al. v. Carol Browner et. al., Case No. 98-356-CIV-Stafford). The TMDLs for ammonia, chlorides, coliforms and iron will be done according to the TMDL development schedule associated with the above-mentioned consent decree. This total phosphorus TMDL documents the maximum daily load that Lake Okeechobee can assimilate and maintain the water quality target; the watersheds that drain into Lake Okeechobee will have TMDLs developed at a later time.

Target Identification

A total phosphorus concentration of 40 parts per billion (ppb) is the selected water quality concentration target for the Lake Okeechobee TMDL. EPA is using the target concentration developed from efforts of the Florida Legislature and South Florida Water Management District. It is anticipated that an in-lake phosphorus concentration of 40 ppb will allow the Lake to attain its designated uses. The water quality target identification was the subject of three public workshops conducted by the Florida DEP and South Florida Water Management District. It was concluded at the end of each of these workshops that 40 ppb was the appropriate water quality target. Further investigations by Florida DEP and the District described below conclude that the water quality target of 40 ppb is historically and ecologically appropriate for the lake.

A yearly mean in-lake phosphorus concentration goal was established at 40 ppb for the pelagic region by the Florida Legislature through the SWIM Act to restore Lake Okeechobee to natural conditions (Federico et al. 1981). A modified version of the Vollenweider (1976) model was used to arrive at this total phosphorus load that is needed for the lake to be a healthy lake system. The model found that on average, the phosphorus and nitrogen loads to the lake were 40 to 34 percent, respectively, above the excessive loading rate. This model was criticized for not taking into account the heterogeneity of the lake and the contribution of phosphorus from the lake's sediments.

As a result, the in-lake phosphorus concentration target of 40 ppb was re-evaluated by Havens and James (1997), considering historical "pre-impact" phosphorus concentration data and the heterogeneity of algal responses to in-lake phosphorus concentrations. Based on historical "pre-impact" data, the total phosphorus concentration goal to return the lake to a healthy condition is between 30 ppb and 50 ppb. Total phosphorus and chlorophyll *a* concentrations are found to be highly correlated in the near-shore areas to the south and west (Walker and Havens 1995). In this area, total phosphorus concentrations are found to be higher during bloom conditions compared to non-bloom conditions. Using this correlation, the total phosphorus concentrations needed to prevent blooms in the near-shore areas should be less than or equal to 48 ppb to 51 ppb ($\alpha<0.05$). The phosphorus concentration target should be most protective of the near-shore area, as this area is the most prone to algal blooms (Havens et al. 1994); this area is where the drinking water intakes are located; and this area is the most utilized for habitat, nesting, fishing and recreation (Havens and James 1997).

James and Havens (1996) conducted a regression analysis to derive a total phosphorus concentration goal to achieve a desired algal bloom frequency. From this study, the regression model provided a near-littoral zone total phosphorus concentration goal of between 36 ppb and 52 ppb. Another regression model generated by plugging in the historic low chlorophyll *a* concentration produced a total phosphorus concentration goal of between 40 ppb to 75 ppb ($r^2=0.88$, $\alpha<0.05$).

The total phosphorus concentration goals produced by these different methods all encompass the original 40 ppb target.

Background

Description of Waterbody

Lake Okeechobee is a large, shallow eutrophic lake located in subtropical south central Florida and is a major feature of the Kissimmee-Okeechobee-Everglades (KOE) system (Figure 1). The KOE system is a continuous hydrologic system extending from Central Florida south to Florida Bay. Lake Okeechobee is the largest freshwater lake in Florida and the second largest freshwater lake within the contiguous United States, covering approximately 730 square miles. Since 1992, the lake has had an average lake wide depth of nine feet. The lake has a maximum storage capacity of 1.05 trillion gallons. Lake Okeechobee is a multipurpose reservoir providing drinking water for urban areas, irrigation water for agricultural lands, recharge for aquifers, freshwater for the Everglades, habitat for fish spawning and waterfowl, flood control, navigation, and many recreational opportunities (SFWMD 1997).

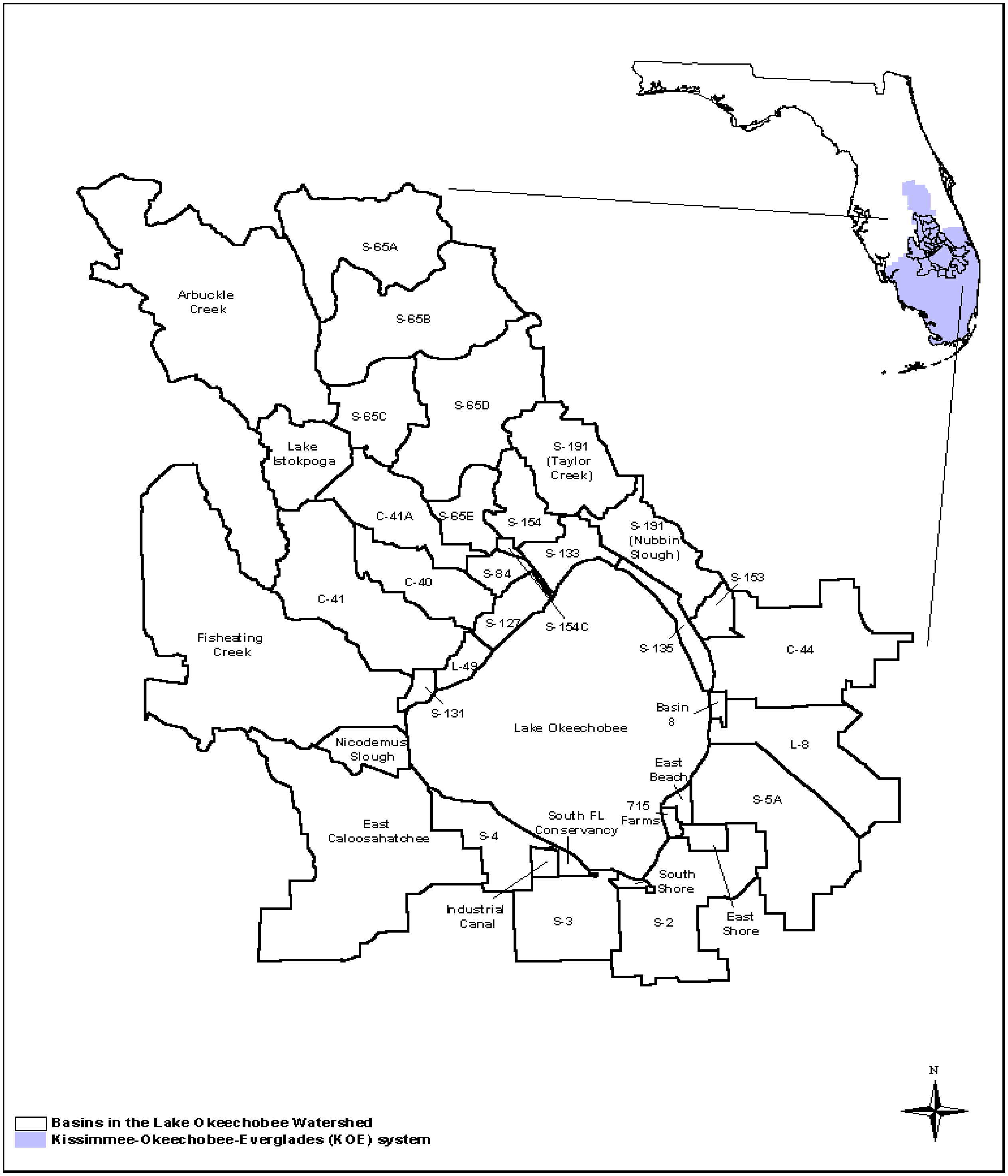

Figure 1. Basins in the Lake Okeechobee Watershed

Figure 1 Basins in Lake Okeechobee Watershed

Lake Okeechobee's drainage basin covers more than 4,600 square miles. The lake's watershed boundary has been defined under the Surface Water Improvement and Management (SWIM) program as those basins that are direct tributaries to the lake, including upstream tributaries and/or basins from which water is released or pumped into the lake on a regular basis (Figure 1). Forty-one basins fall within this boundary. Major hydrologic inflows into the lake include rainfall (39 %), the Kissimmee River (31 %), and numerous smaller inflows, such as discharges from the Everglades Agricultural Area (EAA), Harney Pond basin, Indian Prairie Creek basin, Fisheating Creek, and Taylor Creek/Nubbin Slough. Major hydrologic outflows include evapotranspiration (66 %), the Caloosahatchee River to the west (12 %), the St. Lucie Canal (C-44) to the east (4 %), and four agricultural canals which discharge south into the Everglades region (Miami, North New River, Hillsboro, and West Palm Beach canals) (SFWMD 1997).

Two hundred years ago, Lake Okeechobee was a completely sand-bottom lake (Reddy et al. 1995). However, since the 1950s, increasing rates of sediment deposition and phosphorus accumulation have resulted in the formation of muds over a large portion of the lake bottom (approximately 330 mi^2) (SFWMD 1997, Harvey and Havens 1999). The increased rates of sediment deposition and phosphorus accumulation began 150 years ago, with the most rapid rates occurring in the last 50 years (Reddy et al. 1995).

At low lake stages, Lake Okeechobee is a spatially heterogeneous system and has five distinct ecological zones: littoral, transition, edge, north and center (Figure 2) (Phlips et al. 1995). The ecological zones differ based on water chemistry: total phosphorus, total nitrogen, chlorophyll *a* concentrations, limiting nutrient status and frequency of algal blooms and light availability (Havens 1994). The ecological zones are closely associated with the different sediment types that have formed at the bottom of the lake. Sediment can affect the ecology of the lake with the resuspension of certain sediment types into the water column, which then affects light availability. The littoral zone is covered by emergent and submergent vegetation, covering an area of approximately 150 square miles (25% of surface area), and is primarily located along the western shore (Havens et al. 1996b, SFWMD 1997). The littoral zone is typically found in areas where rock is the underlying sediment. The edge ecological zone is located in the southern and western portions of the lake, between the littoral and the transition zones, and is characterized by low total phosphorus, high light availability, and severe nutrient limitation year round. This ecological zone has developed in areas containing sand and peat. The edge (or near-shore) zone is the most sensitive to lake water levels and nutrient loading. The north zone is located in the northeastern portion of the lake and around the center ecological zone. This area receives high phosphorus loading from the Taylor Creek/Nubbin Slough basins and is characterized by high total phosphorus concentrations and nitrogen-limited phytoplankton growth. The center zone also has high total phosphorus and high chlorophyll *a* concentrations, while photosynthetic growth is typically light-limited (except in the mid-summer) due to the resuspension of the mud sediments below. The transition zone is located between the north and edge zones and has moderate concentrations of total phosphorus. This zone is mostly found overlying sand sediment (SFWMD 1997).

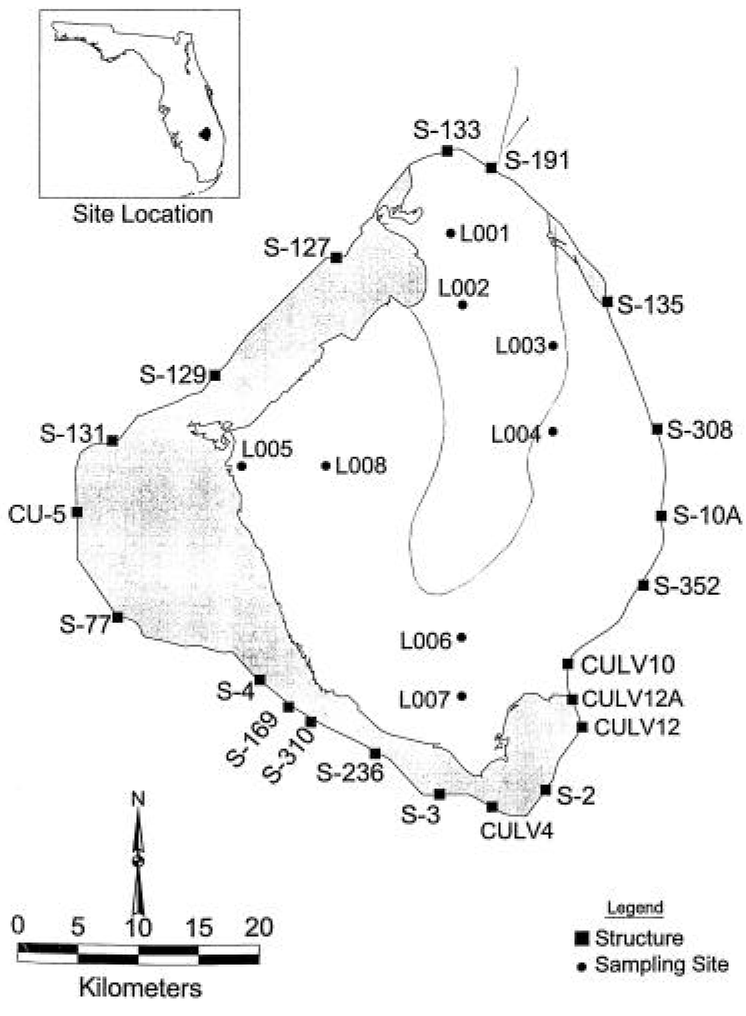

Figure 2 Lake Okeechobee Sampling Stations, Ecological Zones and Control Structures

Hydrology

The pattern of water movement and currents in Lake Okeechobee are typically the result of wind patterns (direction and velocity) and water depth. Distinct patterns are formed on the surface and at the bottom of the lake (SFWMD 1997). The water circulation gyres for both the surface and bottom typically move in a clockwise direction (Sheng 1993). The water found at the bottom of the lake typically moves south, with the presence of one clockwise circulation gyre. The water at the surface is influenced by multiple circulation gyres, all-moving in the clockwise direction (SFWMD 1997). The residence time in Lake Okeechobee is approximately 3 years.

The Lake Okeechobee watershed has little relief and has a water table that is near the soil surface during the wet season; as a result, the area was once composed of large quantities of wetlands (Blatie 1980). The hydrology of the Kissimmee-Okeechobee-Everglades drainage system has been greatly modified with diking and dredging to create farmland, control flooding, provide navigation, and create a water supply (SFWMD 1997). Prior to human modification, the littoral zone of Lake Okeechobee was connected to the Everglades marsh and would deliver sheet flow runoff to the Everglades (Brooks 1974, Tebeau 1984). During the 1920s, flooding resulted in the loss of life and property, and as a result a flood control levee (Herbert Hoover Dike) and a rim canal were constructed around the lake to control flooding (Havens et al. 1996a). Currently, all flows into and out of the lake are managed through 140 miles of canals, control structures (gates, locks, and pumps) and levees, which were completed in the late 1950s, as part of the Central and South Florida (C&SF) Project (Figure 2). The South Florida Water Management District (SFWMD), in conjunction with the United States Army Corps of Engineers (USACE), regulates these structures and canals (SFWMD 1997).

The USACE has developed a lake regulation schedule to control flooding during the wet season and store water for the dry season. This schedule determines the timing and quantity of water releases from Lake Okeechobee based on its water level (Otero and Floris 1994). Over the last 60 years, the schedule of regulatory releases has somewhat varied the lake’s water levels. The levee constructed in 1932 at the south end of lake was the only water control structure within the Lake Okeechobee watershed; and as such, the lake was considered to be at “natural water levels”, which was at an average of 19 feet NVGD. From

1932 to 1950, the lake exhibited high average water levels and low inter-year variability. Then from 1950 to 1977, the lake had lower water levels (14.4 – 16.1 feet) and higher inter-year variability. From the 1960s to 1971, the northern portion of the Lake Okeechobee watershed also experienced hydrological changes. The lower Kissimmee River was channelized, and 40,000 to 50,000 acres of floodplain wetlands were drained for the development of agriculture (Loftin et al. 1990). These modifications upstream of Lake Okeechobee resulted in higher lake levels, which flooded fish-spawning grounds and waterfowl feeding and nesting habitat. From 1978 to 1995, Lake Okeechobee had intermediate water levels (15.4-17.3 feet) and high inter-year variability. Figure 3 presents annual average stage of Lake Okeechobee. The 1999 schedule has the goal of reducing inter-year variability and also reducing pulse releases of freshwater from the lake to the Caloosahatchee and St. Lucie estuaries (LORSS 1996).

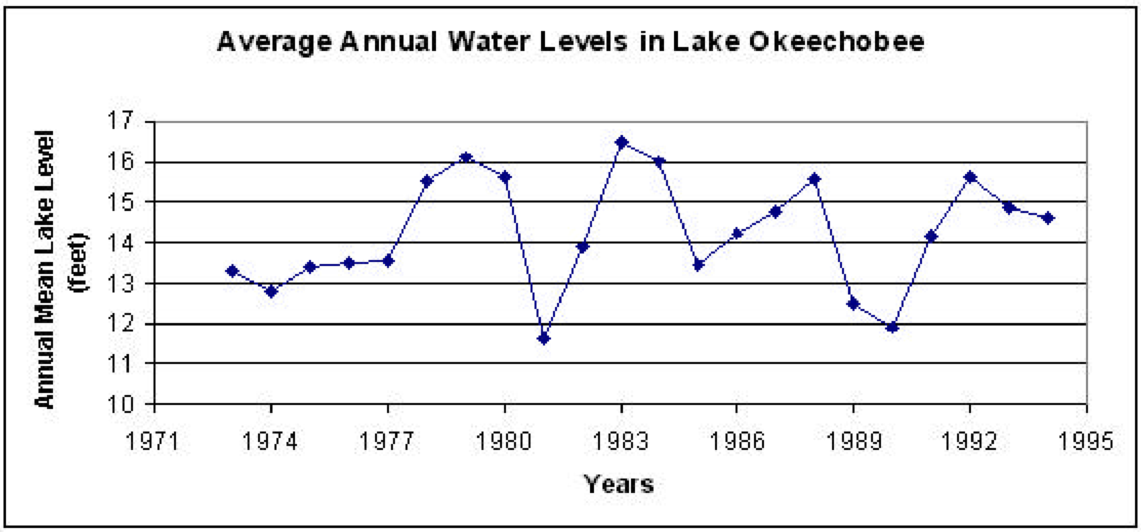

Figure 3 Lake Okeechobee Lake Levels

Water Quality Characterization

Impairment of Use

According to the 1998 Section 303 (d) list established by FDEP, the water quality of Lake Okeechobee is listed as impaired due to phosphorus, dissolved oxygen, iron, un-ionized ammonia, coliforms and chlorides. High phosphorus concentrations and low dissolved oxygen are the predominant reasons for impairment. Elevated phosphorus loadings to the lake and high internal phosphorus concentrations have intensified the eutrophication of the lake, which is evidenced by the development of widespread algal blooms. Low dissolved oxygen is the result of groundwater seeping into the canals, flow from wetlands in the Taylor Creek/Nubbin Slough, Fisheating Creek, Kissimmee River basins, and nutrient loading (Harvey and Havens 1999).

According to Rule 62-302.400 (Florida Surface Water Quality Standards), Lake Okeechobee is designated a Class I water (potable water supply). The State of Florida has a narrative criterion for nutrients, and according to this water quality criterion (Rule 62-302.530(48)), nutrient concentrations of a waterbody shall not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna. The development of seasonal blooms of blue-green algae (Cichra et al. 1995) and the shift in the composition of benthic macroinvertebrates toward more pollutant-tolerant species (oligochaetes) (Warren et al. 1995) are considered to be imbalances. Algal blooms have caused large-scale die-offs of macroinvertebrates due to anoxia and toxic ammonia (Jones 1987). Endotoxins (Carmichael et al. 1985), along with taste and odor problems (Barica 1993), produced by the algal blooms threaten drinking water (Heiskary and Walker 1988). These problems created by algal blooms have resulted in higher costs for treatment of water for potable uses (Barica 1993). High total phosphorus concentrations and the presence of undesirable algal blooms in Lake Okeechobee cause this waterbody to not meet its designated use.

Eutrophication

Researchers observed an increased rate of eutrophication in Lake Okeechobee from 1973 to present. Symptoms of this eutrophication include increases in algal bloom frequency since the mid-1980s, increases in the dominance of blue-green algae as a result in a shift in the TN:TP ratio, increases in the lake water concentration of total phosphorus, and increases in chlorophyll *a* concentrations (Havens et al. 1995). Phosphorus is considered the key element contributing to the eutrophication of the lake (Kissimmee-Okeechobee Basin Report 1972, Federico et al. 1981) because increases in total phosphorus concentrations in the lake, coupled with decreases in nitrogen loading from reduced back pumping from the Everglades Agricultural Area, has shifted the TN:TP ratio from greater than 25:1 in the 1970s to greater than 15:1 in the 1990s, creating conditions more favorable for the proliferation of nitrogen-fixing blue-green algae, which are responsible for the blooms seen in the lake (Smith et al. 1995). An algal bloom is defined by the presence of chlorophyll *a* concentrations greater than 40 ug/L (Maceina 1993, Carrick et al. 1994). At this concentration, the algae noticeably color the lake. Wind-driven sediment resuspension and high summer temperatures seasonally and spatially control algal blooms. The highest light availability in the spring and fall occurs to the west, which results in higher frequencies of blooms. Bloom frequency is correlated with temperature and transparency and negatively correlated with total phosphorus, dissolved inorganic nitrogen and wind velocities. Blooms occur more frequently at the northern pelagic stations (L001 and L002) and in the west (L005 and L008). The lowest frequencies of blooms occur at the center of the pelagic zone (L004 and L006). Overall, the highest frequency of blooms is seen in June. The highest frequency of blooms in the spring and fall occurred at L005 (west), while the highest in the winter and summer occurred at L008 (west-central). Figure 2 illustrates the location of the sampling stations (Havens et al. 1995).

Phosphorus Trends

Total phosphorus concentrations within the pelagic region of the lake have been increasing since the early 1970s (Figure 4). The total phosphorus concentrations that currently exist in the lake are in excess of the amount needed for a healthy ecosystem. The construction of canals and structures, as a result of the C&SF Project, has contributed to the more than doubling of total phosphorus concentrations found in the pelagic region of the lake, expediting the delivery of stormwater runoff from the intensive land uses (agriculture) that have developed in the area (Harvey and Havens 1999). The average concentration of total phosphorus for the last five years in the pelagic region is 100 ppb. Near-shore total phosphorus concentrations are generally lower than concentrations in the pelagic region (Havens 1997).

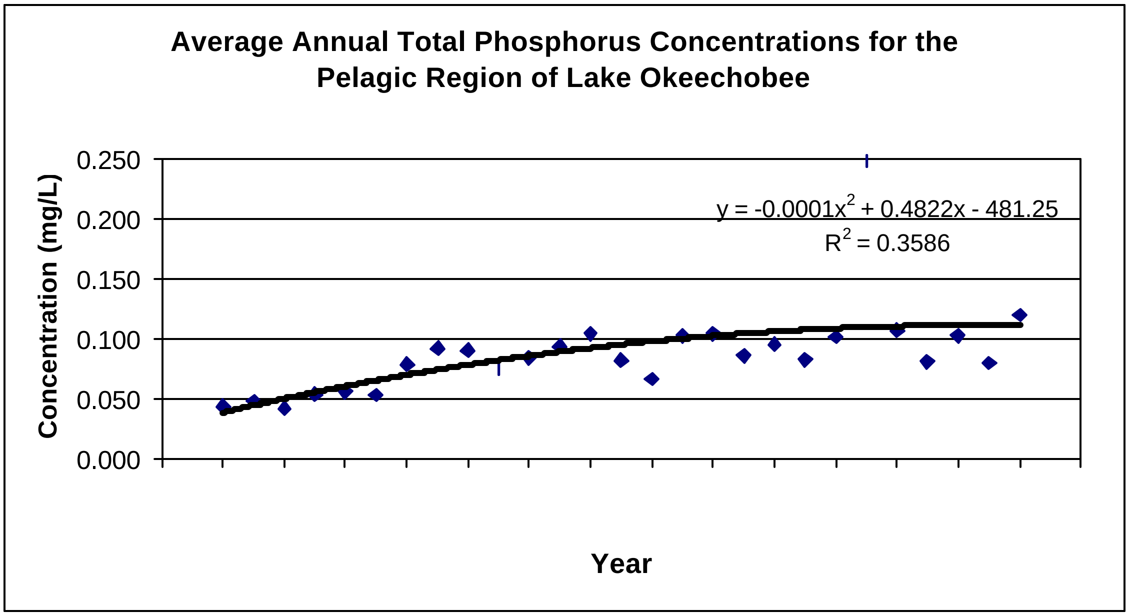

Figure 4 Annual average phosphorus concentrations in the pelagic region

Phosphorus trends in sediments

The concentration of phosphorus in the sediments of Lake Okeechobee has also been increasing. Prior to the 1950s, the lake bottom was comprised primarily of sand with low phosphorus content (Harvey and Havens 1999). According to Engstrom and Benzonik (1993), phosphorus accumulation rates have increased between the 1950s and 1980s. This phosphorus accumulation is resulting in the development of mud sediments. It is estimated that the lake sediments contain approximately 30,000 metric tons of phosphorus (Havens 1997). This stored phosphorus is a significant potential source of phosphorus to the water column when the chemistry of the overlying water changes. Phosphorus loading rates from the sediments to the water column are 0.7 mgP/m^2/day for mud and 1.1 mgP/m^2/day for marsh sediments (Reddy et al. 1995). Currently, the internal phosphorus loading from the sediments to the water column is equal to the external phosphorus loading on an annual basis (Reddy et al. 1995). High phosphorus loading to the lake saturates the sediments with phosphorus, which is decreasing the lake's capacity to assimilate phosphorus (James et al. 1995).

Total phosphorus stored in the soils of the Lake Okeechobee watershed increases with the intensity of land uses: unimpacted-44gP/m^2, forage-46gP/m^2, pasture-102gP/m^2, intensive agricultural areas-766gP/m^2, streams-116gP/m^2, and wetlands-75gP/m^2. Total phosphorus concentrations in soils within the Taylor Creek/Nubbin Slough basins have increased 50-60 fold in the agricultural areas as a result of phosphorus loading from manure. The phosphorus content of pastures has increased 3-4 fold. Phosphorus retention in upland sediments is 85%, however continuous loading of these soils is decreasing the retention capacity of the soil (Reddy et al. 1995).

Current Lake-Wide Phosphorus Loading

Phosphorus loading rates to Lake Okeechobee have averaged approximately 570 metric tons/year over the past 10 years. The average output of 150 metric tons/year leaves the system each year through the structures. This leaves 420 metric tons/year of phosphorus as sediment on the bottom of the lake. On an annual basis, the phosphorus stored in the lake's sediments is adding phosphorus to the water column at a rate almost equal to the external loading of phosphorus. To address excess phosphorus loadings to Lake Okeechobee, phosphorus-loading targets for each of the contributing basins within the watershed were established by the SWIM Act of 1989 to rehabilitate the ecological condition of the lake (SFWMD 1989). The SWIM Act specified a 40% reduction in phosphorus loading in an effort to achieve an in-lake total phosphorus concentration of 40 ppb (Federico et al. 1981). This equates to a total phosphorus load to the lake of 400 metric tons/year (SFWMD 1993). Since 1991, phosphorus-loading rates have exceeded the 1989 SWIM target by over 100 metric tons/year (Harvey and Havens 1999). Twenty basins are exceeding their targets, while twelve basins are at or below their targets. Four basins have been identified as the key contributors of phosphorus: TCNS, S-154, S-65D, S-65E, which are Taylor Creek, Nubbin Slough, and the Kissimmee River. Many dairies and other land uses are out of compliance with their permits in these basins. Table 1 provides the SWIM phosphorus loading targets for each basin, along with their current phosphorus loading rates.

Table 1 Current phosphorus loads rates and target phosphorus loading rates for each basin (SFWMD 1997).

Basin Controllable Sources	Discharge (acre-ft)	Area (sq. mi)	SWIM Target TP (ppm)	SWIM Target Load(short tons/yr)	Actual TP (ppm)	Actual Load (short tons/yr)	Over Target (short tons/yr)

Basin Controllable Sources	Discharge (acre-ft)	Area (sq. mi)	SWIM Target TP (ppm)	SWIM Target Load(short tons/yr)	Actual TP (ppm)	Actual Load (short tons/yr)	Over Target (short tons/yr)
715 Farms (Culv 12A)	12,758	4	0.18	3.1	0.1	1.7	-1.4
C-40 Basin (S-72) – S68*	16,069	87	0.18	3.9	0.2	10.5	6.6
C-41 Basin (S-71) – S68*	52,768	176	0.18	12.9	0.18	32.3	19.4
S-84 Basin (C41A) – S68*	66,759	180	0.1	9.1	0.05	12.9	3.9
S-308C (St. Lucie-C-44)	41,480	190	0.18	10.2	0.13	8.9	-1.2
Culvert 10	11,612	10	0.18	2.8	0.53	9.8	7
Culvert 12	15,075	13	0.13	2.7	0.18	3.6	1
Fisheating Creek	256,761	462	0.18	62.8	0.18	60.7	-2.1
Industrial Canal	21,878	23	0.18	5.4	0.09	2.8	-2.6
L-48 Basin (S-127)	31,088	32	0.18	7.6	0.21	9.4	1.8
L-49 Basin (S-129)	0	19	0.18	0	0.09	2	2
L-59E	nd	15	0.16	nd	nd	nd	nd
L-59W	nd	15	0.16	nd	nd	nd	nd
L-60E	nd	6	0.1	nd	nd	nd	nd
L-60W	nd	6	0.1	nd	nd	nd	nd
L-61E	nd	22	0.09	nd	nd	nd	nd
L-61W	nd	22	0.09	nd	nd	nd	nd
Taylor Creek/Nubbin Slough (S-191)	116,022	188	0.18	28.4	0.57	94.2	65.8
S-131 Basin	11,992	11	0.15	2.4	0.12	1.9	-0.5
S-133 Basin	30,004	40	0.18	7.3	0.16	7.2	-0.2
S-135 Basin	30,097	28	0.16	6.5	0.1	4.3	-2.2
S-154 Basin	23,428	37	0.18	5.7	0.76	22.8	17
S-2	34,629	166	0.16	7.5	0.18	9	1.5
S-3	13,429	101	0.15	2.7	0.18	3.9	1.1
S-4	40,921	66	0.18	10	0.18	11.1	1.1
S65E – S65	364,526	749	0.18	89.2	0.18	91.5	2.3

Basin Controllable Sources	Discharge (acre-ft)	Area (sq. mi)	SWIM Target TP (ppm)	SWIM Target Load(short tons/yr)	Actual TP (ppm)	Actual Load (short tons/yr)	Over Target (short tons/yr)
S-236	9,716	15	0.09	1.2	0.1	1.5	0.3
Culvert 4A	8,954	7	0.08	1	0.09	1.1	0.2
Culvert 5	nd	28	0.06	nd	nd	nd	nd
Controllable Totals	1,209,967			282.7		403.4	120.7
Rainfall					0.03	71	
S65 (Lake Kissimmee)	1,139,602				0.08	119.4	
Lake Istokpoga (S-68)	342,212				0.04	22.4	
S5A Basin	0					0	
E. Caloosahatchee (S-77)	0					0	
L-8 Basin (Culv 10A)	60,922				0.1	8.3	
Uncontrollable Totals	1,542,737					221	
Average Total Loadings						624.3	
Basin Target						503.6	
Vollenweider Target						458.7	
Over-Target Loads				Conc. based	120.7		

Sources of Pollution to the Watershed

Human activities occurring within the Lake Okeechobee watershed have contributed to the high external phosphorus loading rates. Sources of pollution to the watershed are both point and nonpoint sources.

Point Sources

Several point sources exist in the Lake Okeechobee watershed; however, none discharge directly to the lake (Table 2). The specific wasteload allocation to these point sources are not accounted for in this TMDL, but will be addressed when the TMDL for the listed watersheds are established in the future.

Point sources include discharges of effluent from wastewater treatment or industrial facilities. These discharges require permits from DEP known as National Pollution Discharge Elimination System (NPDES) permits, along with FDEP approved water quality-based effluent limits (WQBEL) or technical-based effluent limits (TBEL) for surface water discharges.

Table 2 Sources of Pollution in the Lake Okeechobee Watershed (SFWMD 1997)

Sources of Pollution	Type	Total Number Permitted
Industrial Wastewater Facilities	Point	69
Domestic Wastewater Facilities (Municipal and Private)	Point	121
Dairies	Nonpoint	29
Works of the District (Agricultural, Industrial, Commercial, NPS BMPs)	Nonpoint	688
Surface Water Management (Stormwater Management Systems)	Nonpoint	470
Waste Disposal Systems (landfills)	Nonpoint	16

Nonpoint Sources

Nonpoint sources are the dominant forms of pollution in the Lake Okeechobee watershed, and are a result of different land use practices (Table 2). Stormwater runoff from agricultural land uses is the dominant source of pollution to the watershed. Agricultural activities surrounding the lake dominate the land use in the area, and are responsible for discharging large quantities of nutrients to the waters within the watershed (Anderson and Flaig 1995). Approximately, 50% of the Lake Okeechobee watershed is used for agriculture (Figure 7). Cattle and dairy pasturelands are the primary agricultural activities north and northwest of the lake, while cropland (sugarcane and vegetables) dominates to the south and east of the lake (SFWMD 1989). The most intensive land use in the watershed is dairy farming, which began in the 1950s (Reddy et al. 1995). There is a high correlation between phosphorus imports (animal feed and fertilizers) to the watershed and phosphorus loading to the lake (Boggess et al. 1995). For improved pastures, 34% of the phosphorus imports is fertilizers and 35% is dairy feed (Boggess et al. 95). Other land uses in the watershed consist of wetlands (16%), Upland Forests (10%), Water (7%), Rangeland (7%), Urban and Built-up (10%), Barren Land (1%), and Transportation and Utilities (1%). While urban land uses make up 10% of total area, they only contribute 3% of the total phosphorus load in the watershed (SFWMD 97). Another source of nonpoint pollution is improperly maintained or overloaded residential septic tank waste disposal systems, which deliver contaminants (bacteria and toxic household chemicals) and nutrients to Lake Okeechobee's north and south rim canal.

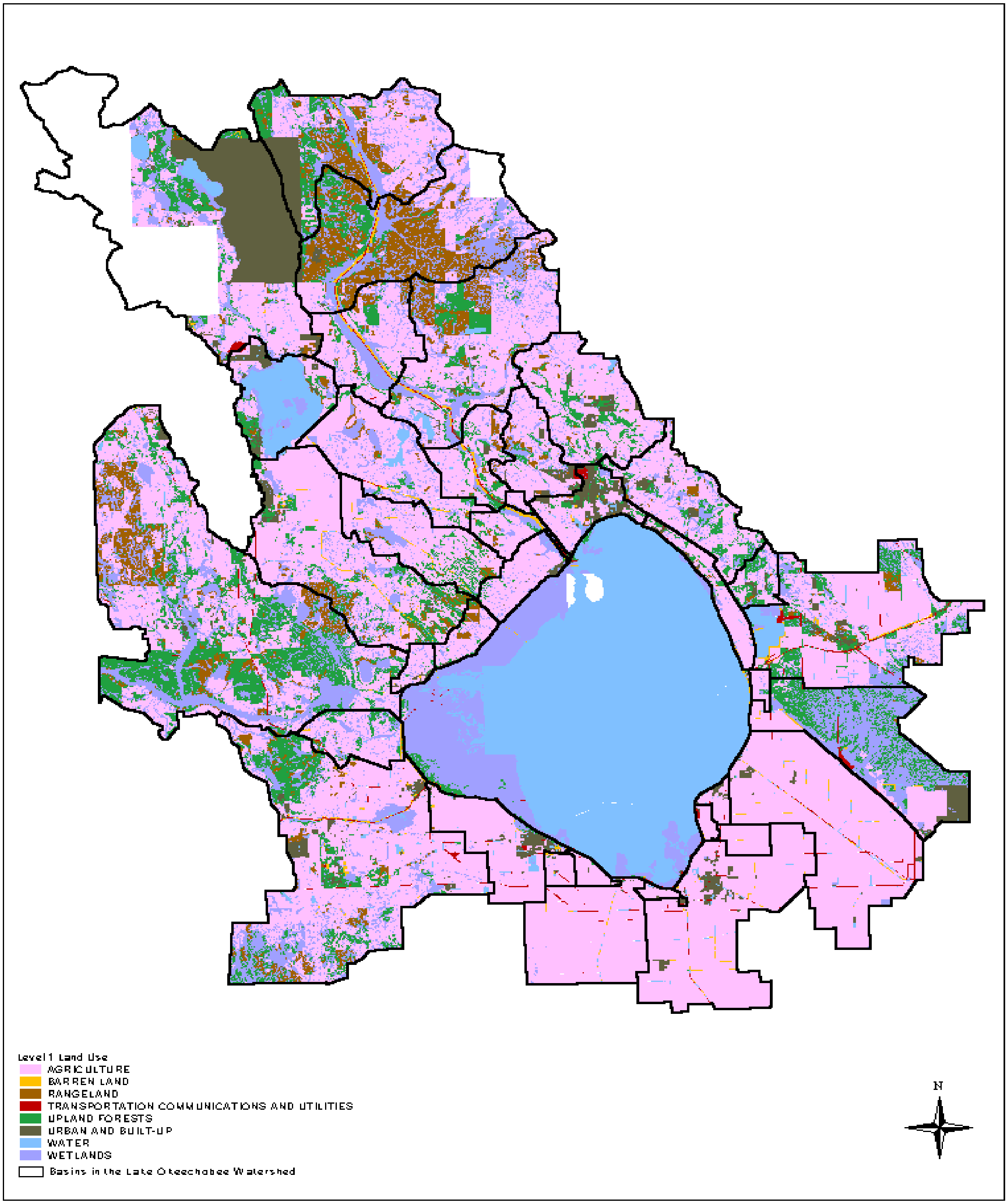

Figure 7. Land Use (Level 1) in the Lake Okeechobee Watershed

Figure 5 Land Use (Level 1) in the Lake Okeechobee Watershed

Reasons for High Phosphorus in Lake Okeechobee

The high phosphorus concentrations in Lake Okeechobee are controlled by watershed activities and in-lake processes (SFWMD 1997). The contributions of phosphorus from the watersheds draining into Lake Okeechobee have occurred over the past 50-60 years. These loadings have caused significant increases in the lake sediment phosphorus concentrations that influence the water quality during low dissolved oxygen conditions and wind events.

Loadings

Phosphorus enrichment and the increase in the frequency of high chlorophyll *a* concentrations (algal blooms) is a result of excessive phosphorus loading to Lake Okeechobee from upstream basins (Reddy and Flaig 1995). Phosphorus loading rates and their sources are discussed above.

Flooding of the Littoral Zone (High Water Levels)

Changes in the Lake Okeechobee water-level regulation schedule exacerbate the problem of eutrophication in the lake by causing higher maximum and lower minimum water levels. In the 1970's, the SFWMD raised the water level of the lake, flooding hundreds of acres of wetlands. This resulted in an increase of phosphorus in the water column. The phosphorus is released from dead and dying vegetation in the littoral region into the water column. A significant correlation between lake level and total phosphorus was found for the period of 1973 to 1984 ($r=0.70$, $p<0.01$) (Canfield and Hoyer 1988). However, water level and total phosphorus are not related for the long-term period from 1953 to 1995 ($r=0.50$, $p<0.05$) (Havens 1997). Dierberg (1992) estimated that the total phosphorus concentrations in the water column increased by 3 ppb due to the complete flooding of submerged macrophytes (not sediments). However, this concentration alone isn't enough to contribute to the overall long-term average increase in total phosphorus in the lake. A study by Harris et al. (1995) also agreed with this. The littoral zone is typically a sink, not a source, for phosphorus (Dierberg 1993).

Internal Loadings from Sediment

Another factor that controls phosphorus on the lake involves the internal phosphorus loading from the consolidated organic muds at the center of the lake bottom (Havens 1997). Sixty percent of the pelagic bottom is composed of these consolidated organic muds, which store approximately 30,000 metric tons of phosphorus. This phosphorus is typically bound to calcium, other organic matter, or iron at the surface of the sediments. The diffusive flux of phosphorus between the surface and water column is controlled by iron solubility. Under reducing conditions (low dissolved oxygen where iron is in the form of Fe^{2+}), phosphorus is released at high rates from the sediment into the water column. Therefore, under conditions of low dissolved oxygen, the levels of phosphorus in the water column could increase from 50 ppb to over 1 ppm. This condition could contribute to the algal blooms that occur in summer months (Olila and Reddy 1993). Despite decreases in external phosphorus loadings, internal phosphorus loading has kept the concentration of total phosphorus in the water column at 90 ppb to100 ppb since the 1980s (Harvey and Havens 1999). This is a common effect seen in shallow lakes with a long history of excessive external phosphorus inputs (Sas 1989).

Wind Effects

A third factor that affects phosphorus in the lake involves wind effects on sediment resuspension. The almost daily wind-driven resuspension increases phosphorus concentrations in the water column (Havens et al. 1996a). Wind and total phosphorus concentrations have a high correlation (r^2=0.78), which is a higher correlation than that between water level and total phosphorus. The highest sediment resuspension in Lake Okeechobee occurs in the winter (Grimard and Jones 1992, Havens et al 1994). Sediment resuspension typically occurs over the consolidated muds in the pelagic zone. This is one of the reasons for the constant high total phosphorus found in the pelagic zone. These total phosphorus concentrations remain high even when external phosphorus loading decreases (Harvey and Havens 1999).

Available Monitoring Data

Water quality has been monitored in Lake Okeechobee by many agencies since the late 1960s, including the South Florida Water Management District (SFWMD), Florida Department of Environmental Protection (FDEP), United States Army Corps of Engineers (USACE), United States Environmental Protection Agency (USEPA), county governments, universities, and private organizations. The lead organization for monitoring Lake Okeechobee has been the SFWMD. The data used for the development of the TMDL was based on the near-shore stations monitored by the SFWMD since 1973.

Numeric Targets and Sources - Model Development

A water quality model has been developed by the South Florida Water Management District (James, 1995) to investigate management strategies for Lake Okeechobee. The Lake Okeechobee Water Quality Model (LOWQM) has been developed and refined to best parameterize the nutrient fate and transport within this large waterbody. The model has been successfully calibrated to a substantial dataset (1978-1997). This model was used to determine the assimilative capacity of Lake Okeechobee, evaluate different loading alternatives and project the time it will take the lake to return to acceptable water quality based on loading alternatives.

As with any model there is a level of uncertainty with the projections, especially when projections into the future are made. It is difficult to quantify uncertainty inherent to dynamic water quality models like the one being applied to Lake Okeechobee. The South Florida Water Management District performed sensitivity analysis on the model calibration by varying the rates and constants in the model that exert the most control over model predictions. Additional information and data will be collected in the future that will be used in future modeling scenarios to reduce the uncertainty in the model results. Currently, LOWQM represents the best tool for developing and evaluating TMDL scenarios for Lake Okeechobee.

Total Maximum Daily Load (TMDL)

The TMDL is the total amount of pollutant that can be assimilated by the receiving water body while achieving the water quality target. The TMDL will set the maximum average annual load of Total Phosphorus to Lake Okeechobee to achieve the water quality target of 40 ppb within a reasonable time period.

Assimilative Capacity Determination

The assimilative capacity of Lake Okeechobee represents the maximum load the lake can incorporate without causing a change in the in-lake and sediment phosphorus concentrations. The assimilative capacity was determined by using the Lake Okeechobee Water Quality Model.

The LOWQM model was parameterized to 1910 measured sediment concentrations (90 mg/l total phosphorus) and the current atmospheric load (71 tons). Several scenarios were developed to determine the assimilative capacity of Lake Okeechobee. These scenarios involved changing the inflow phosphorus concentrations. The annual load that is associated with the given inflow concentration is presented in Table 3.

Table 3 Assimilative Capacity Determination

Inflow Concentration (mg/l)	Metric Tons/Year
0.085	288
0.084	285
0.080	275

The annual average load to Lake Okeechobee was adjusted until there was no net accumulation of phosphorus in the lake sediments. This represents the maximum load Lake Okeechobee can assimilate without causing an increase in the lake's total phosphorus concentration when an in-lake total phosphorus concentration of 40 ppb is achieved. Figure 6 illustrates the predicted sediment concentrations for Lake Okeechobee over time. The phosphorus load that does not cause an increase of phosphorus in lake sediments is 285 metric tons/year. This represents the maximum assimilative capacity of Lake Okeechobee. A projected trend line for the maximum assimilative capacity indicates the waterbody will reach the target of 40 ppb.

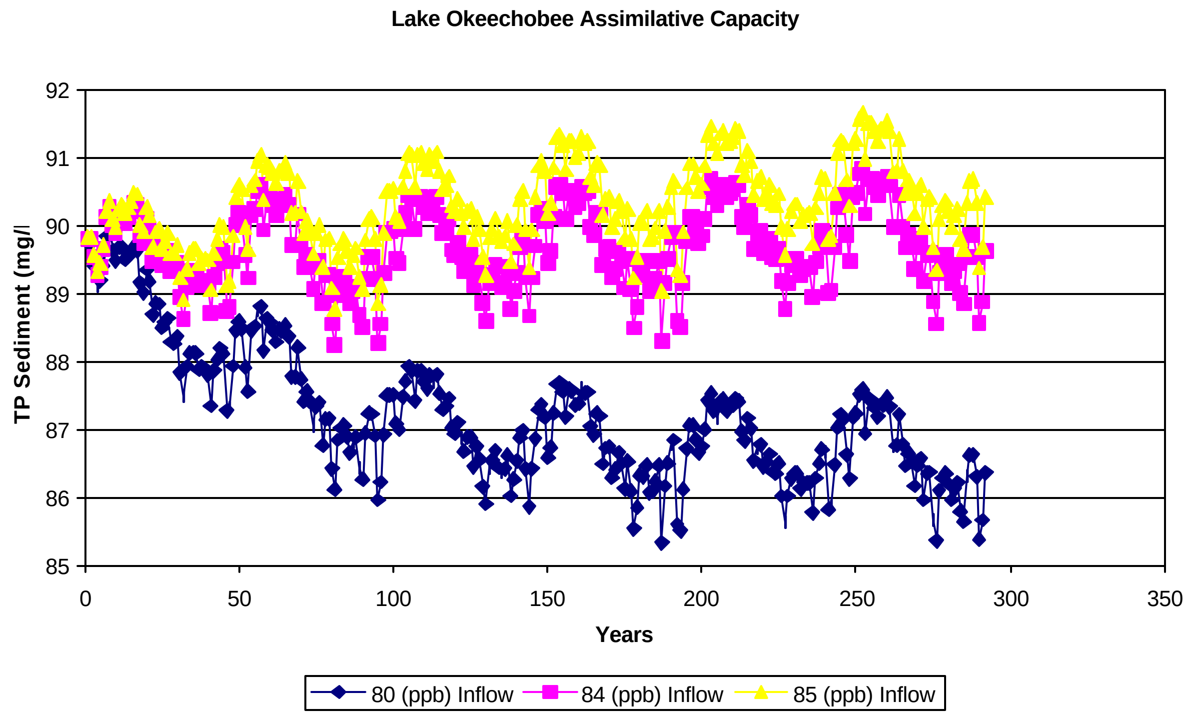

Figure 6 Lake Okeechobee Assimilative Capacity Simulations (Sediment Concentrations)

Figure 7 illustrates the response of the water column concentration to loading scenarios. Because of changes in inflow and the affects of sediment resuspension events on water column phosphorus concentrations it is difficult to determine the trend in the water column. Trend analysis indicates that the water column concentration is decreasing with time.

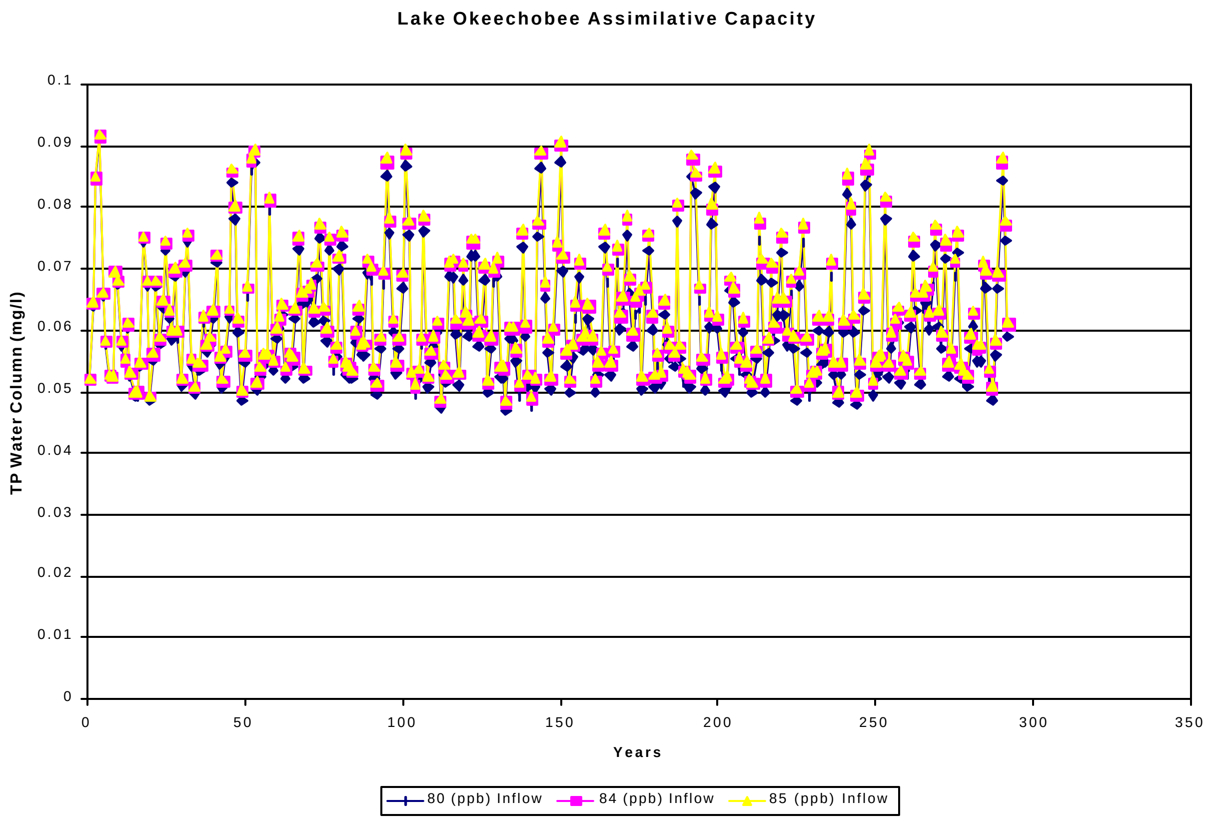

Figure 7 Lake Okeechobee Assimilative Capacity Simulations (Water Column)

The figures demonstrate the capacity Lake Okeechobee could assimilate given 1910 sediment conditions and the current atmospheric load. It is important to note that today's current load to Lake Okeechobee is more than twice the assimilative capacity calculation.

Critical Condition Determination

This TMDL establishes the maximum annual load for phosphorus for Lake Okeechobee. The LOWQM model represents critical conditions by utilizing 26 years of data that represents the range of flow and meteorological conditions that can occur in Lake Okeechobee. The lake does not experience extreme conditions because all flows into and out of the lake are controlled by a regulation schedule.

Seasonal Variation

Seasonal variation is considered in the LOWQM model. The model accounts for changes in flow, meteorological conditions, and algal dynamics on water quality utilizing a 26-year period of record for Lake Okeechobee. Seasonal variation is important to this TMDL, because the water quality target was selected to protect the lake against algal blooms.

Margin of Safety

A margin of safety (MOS) is required as part of a TMDL in recognition of the many uncertainties in the scientific and technical understanding of the chemical and biological processes that occur in Lake Okeechobee. Furthermore, there are uncertainties associated with the model projections into the future. The MOS is intended to account for such uncertainties in a conservative manner that protects the environment. According to EPA's guidance, a MOS can be achieved through reserving a portion of the load for the future, or using conservative assumptions in calculating the load. In the case of Lake Okeechobee, the MOS is accounted for by establishing a TMDL at a loading value below the loading value predicted by the model at the maximum assimilative capacity. This MOS will insure that the loading determination is conservative and the water quality of the lake will be protected.

TMDL Determination

The determination of the Total Maximum Daily Load for Lake Okeechobee includes a consideration for the time period required for the lake to respond to the TMDL. In the case of Lake Okeechobee, EPA is proposing a TMDL of 198 metric tons per year of total phosphorus that includes 71 metric tons per year total phosphorus for atmospheric sources. The 198 metric tons of total phosphorus accounts for the long recovery time of the lake due to nutrient cycling from the sediments.

Several scenarios considered by EPA in determining the TMDL for Lake Okeechobee are presented in Table 4**.**

Table 4 TMDL Determinations

Inflow Concentration (ppb)	**TMDL (tons/year)**	**Recovery Time (Years)**	**% Load Reduction** **Based on 1997 624 tons/yr**
0 (Atmosphere Only)	71	20-30	89%
40	173	180-200	72%
50 (EPA proposed TMDL)	198	200-220	68%
60	224	300-500	64%
70	250	800-1000+	59%
80 (Maximum Assimilative Capacity)	275	1000-1500+	56%

Because of the large quantity of phosphorus contained in the sediments due to a long history of high phosphorus loads to the system, the time for the lake to recover is substantial. Table 4, Figure 8 and Figure 9 illustrate the response of total phosphorus to six different phosphorus-loading scenarios.

It should be noted that any of the scenarios would eventually allow the lake to recover to its pre-impacted conditions of an in-lake phosphorus concentration of 40 ppb at some point in the future.

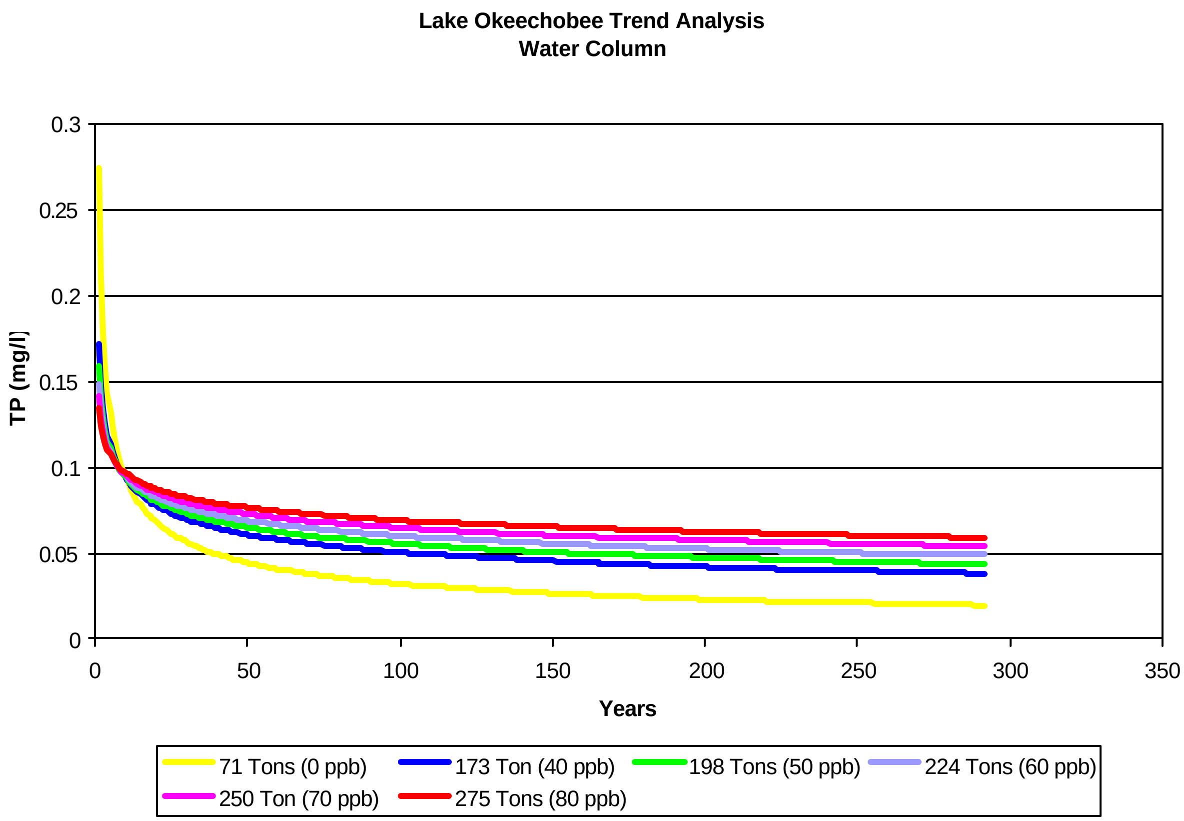

Figure 8 Lake Okeechobee Trend Analysis for different Loading scenarios

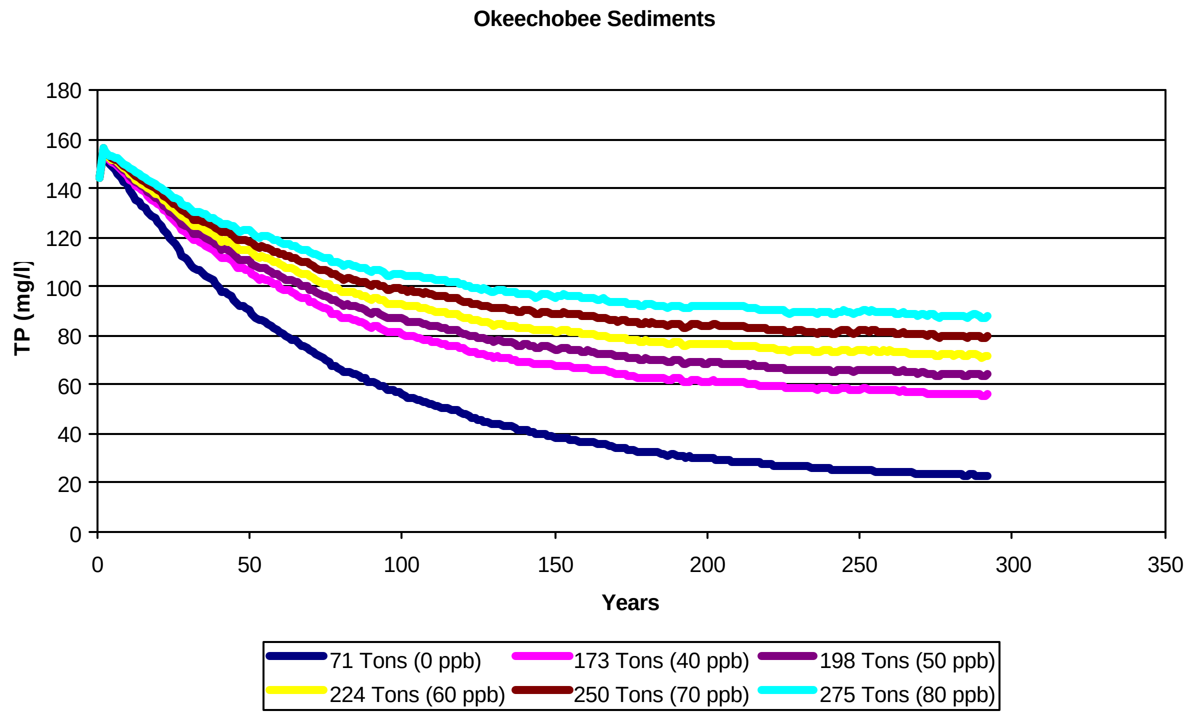

Figure 9 Total Phosphorus Responses to TMDL Scenarios (Sediment)

Figure 10 and Figure 11 illustrate the response of the in lake phosphorus concentrations to the various loading scenarios for the first 30 years. It should be noted that in the short term (first 30 years) the relative difference or change in phosphorus concentrations are relatively similar among the scenarios. This is indicative of the level of phosphorus in the sediments and the time required for them to be flushed out of the system.

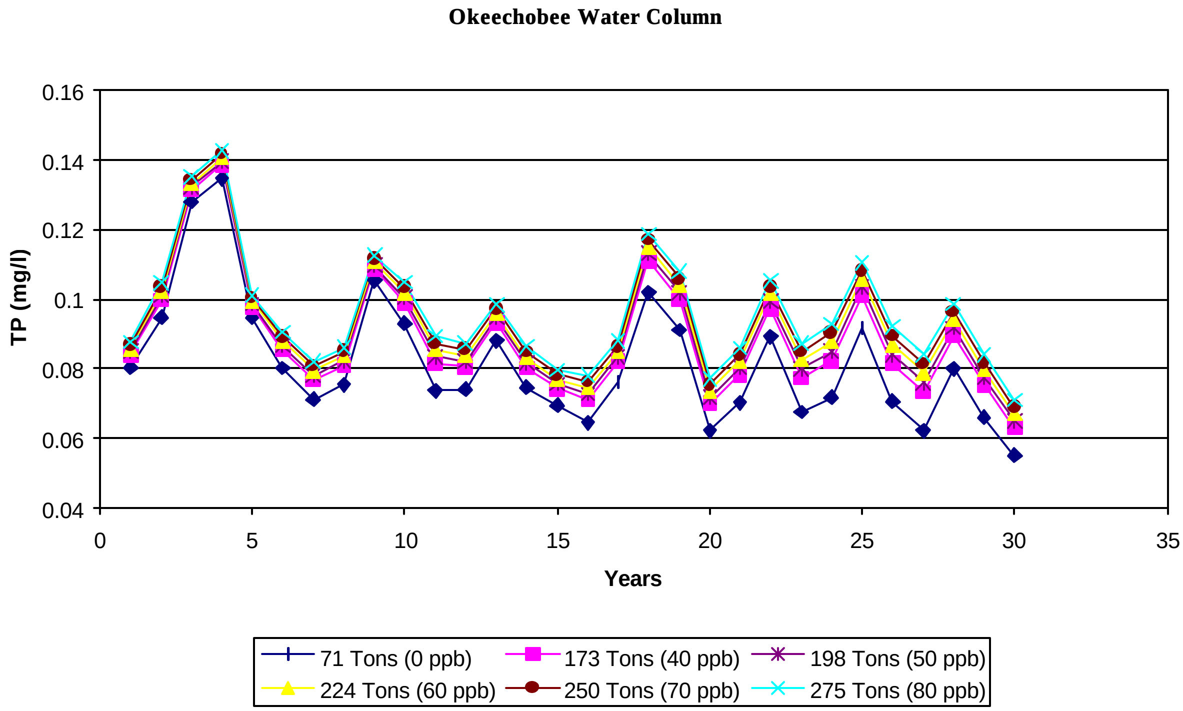

Figure 10 Total Phosphorus Responses to TMDL Scenarios First 30 Years (Water Column)

The overall recovery of Lake Okeechobee will be determined by how fast the sediments respond to changes in load. The quicker the phosphorus concentration is reduced in the sediments the faster the lake water column concentrations will be reduced.

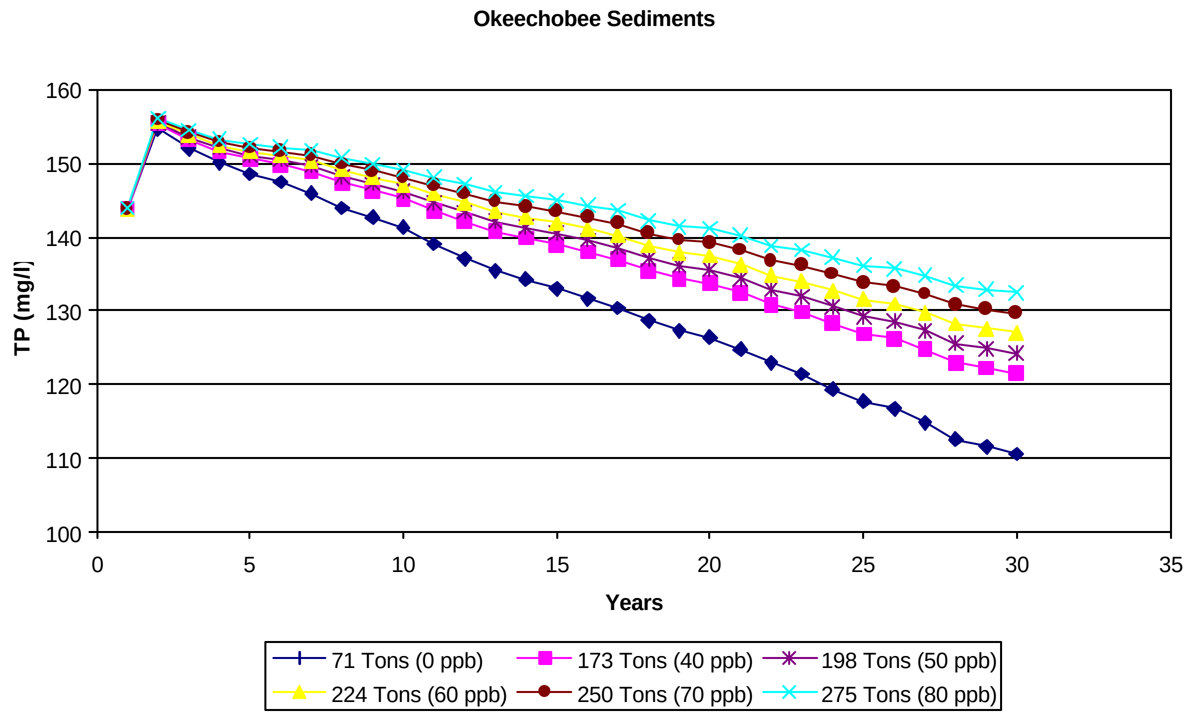

Figure 11 Total Phosphorus Responses to TMDL Scenarios First 30 Years (Sediments)

EPA proposes a TMDL of 198 metric tons per year of total phosphorus to Lake Okeechobee. This proposed TMDL represents the environmental benefit in selecting a scenario for the TMDL with a lower loading rate that will allow for a reasonable recovery time. This translates to approximately 50 parts per billion as the average inflow concentration of total phosphorus to the system.

The proposed TMDL for Lake Okeechobee is 198 metric tons of Total Phosphorus per year including atmospheric sources of 71 metric tons per year.

Allocation of Responsibility and Recommendations

The proposed TMDL for Lake Okeechobee is 198 metric tons total phosphorus per year. This TMDL is not allocated to the individual structures entering Lake Okeechobee; instead this allocation is given to the sum of all loads entering Lake Okeechobee.

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Model/Input/Output

The Lake Okeechobee water quality model input/output information is available and is stored on US EPA Region 4 computer system. This contains all of the information that was used to determine the assimilative capacity of Lake Okeechobee and project the time period for the lake to recover using the different load scenarios. This series contains 144 files.